Chapter 1

Overview of Completed Projects

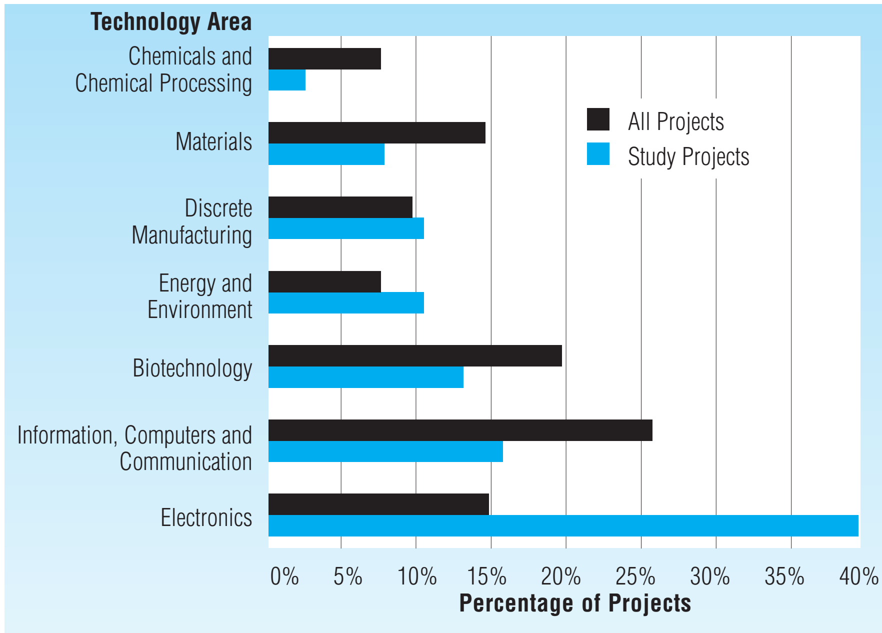
Characteristics of the Projects

The 38 completed projects within the ATP portfolio differ in many respects. They vary in terms of costs, duration, form (single applicant or joint venture), industry, size of company, public/private ownership status, type of participating organizations, research problems addressed, technology developed and the degree of progress made toward meeting technical and business goals.

Single Applicants and Joint Ventures

Thirty-four of the completed projects were proposed by single applicants, with the other four being proposed by joint ventures. For the majority of the first-completed projects to be single applicants was expected, since 285 of the 431 projects announced through 1998 were single-applicant projects, while 146 were joint ventures. Also single-applicant projects tend to be shorter in duration, completing sooner than most joint ventures. Thirty-three of the single applicants were for-profit companies, and one was a nonprofit institute.[1]

Figure 1. Distribution of Projects by Technology Area



Size of Companies

Among the thirty-three companies in single-applicant projects, 27 were small companies, where "small" is defined as having fewer than 500 employees. One was a medium-sized company, and the other five were large companies, as defined as Fortune 500 or equivalent firms. Small companies also participated in joint venture projects, but these are not separately identified here.

Public and Private Companies

Of the 27 single applicants that were small companies, 21 were privately held companies at the time their projects started. A number of these have since gone public, as discussed later in this chapter.

A Variety of Technologies

The 38 completed projects fall into seven different technology areas, as shown in Figure 1, where percentages of the 38 completed projects within the areas are shown in the lower of the two bars. The highest concentration, with 15 projects, is in Electronics, followed by Information, Computers and Communication, with six. The lowest is in Chemicals and Chemical Processing, with only one project. For comparison purposes, Figure 1, also shows, in the upper of the two bars, the distribution across the same seven technology areas for all 431 projects awarded through 1998. The Electronics area is much more strongly represented in the set of 38 completed projects reviewed in this study than in the portfolio of all ATP projects.

Table 1. Single-Applicant Project Cost

	ATP Share Total		(ATP + Industry)	
(millions)	Number of Projects	Percentage of Total Projects	Number of Projects	Percentage of Total Projects[2]
≤ $1	5	15%	2	6%
> $1, ≤ $2	29	85%	5	15%
> $2, ≤ $3			14	41%
> $3, ≤ $4			5	15%
> $4, ≤ $5			5	15%
> $5, ≤ $6			3	9%
Total	**34**		**34**	

Table 2. Joint Venture Project Cost

	ATP Share Total		(ATP + Industry)	
(millions)	Number of Projects	Percentage of Total Projects	Number of Projects	Percentage of Total Projects
≤ $5	3	75%	1	25%
> $5, ≤ $10	1	25%	1	25%
> $10, ≤ $15			2	50%
Total	**4**		**4**	

Duration of Projects

The 38 projects also varied in duration. The median length was three years, the maximum allowable length for single-applicant projects. Half of the projects lasted 33 to 36 months. Another group clustered around the two-year mark. The two projects that lasted longer than 36 months were joint venture projects, which can last a maximum of five years.

Differences in Costs of the Projects

The 38 projects varied significantly in terms of cost, as shown in Tables 1 and 2. Both the ATP share and the total cost (ATP share plus industry share) are tabulated. Joint venture projects, for which project costs are not capped, typically cost more than single-applicant projects, but even within the two groups, marked differences occur.

Rules concerning the share of project costs the ATP will contribute differ between single applicants and joint ventures. Single-applicant companies are required to cover all their indirect costs, and the ATP may cover up to 100 percent of direct project costs.[3] Since projects from small companies typically have smaller indirect costs relative to direct costs, it is likely that the ATP will contribute a larger percentage of total project costs for these projects than for others. The large percentage of single-applicants that are small companies (27 out of 34) accounts for the fact that ATP paid more than half the costs for many of these projects.

The cost-share rules affect the cost data presented in the 38 individual project reports (displayed project by project in Chapters 2-8). Tables 1 and 2 are based on those data. For the 34 single applicants, the industry contribution to their indirect costs is the amount given in the original ATP proposal, unless the company supplied a different amount for this study. None of these amounts was audited. For the remaining four projects, the industry contribution shown is the amount actually spent by project participants, as audited.

Among the 34 single-applicant projects, two had total costs (ATP + industry) of a million dollars or less. At the other end of the cost range, three projects had total costs between $5 million and $6 million. Altogether, approximately $98.4 million was spent for the 34 single-applicant projects, with an average total cost of about $2.9 million per project.

Cost data for the four joint ventures are summarized in Table 2. The smallest project, included in the first row, had a total cost (ATP + industry) of less than $2 million. The largest, included in the third row, had a total cost of almost $14 million. Altogether, approximately $31.9 million was spent on the four projects. The average total cost per joint venture project was about $7.9 million.

The ATP contributed $64.6 million to the 38 projects, providing slightly less than half the total funds. It contributed more than 50 percent of the total cost for 19 projects and less than 50 percent for 19. In the case of the joint ventures, the ATP's contribution was always less than half of total costs.

Timeline of Expected ATP Project Activities and Impacts

The ultimate success of the ATP projects is determined by activities and impacts that occur within the award-recipient companies and in the larger economy before, during and after each project.

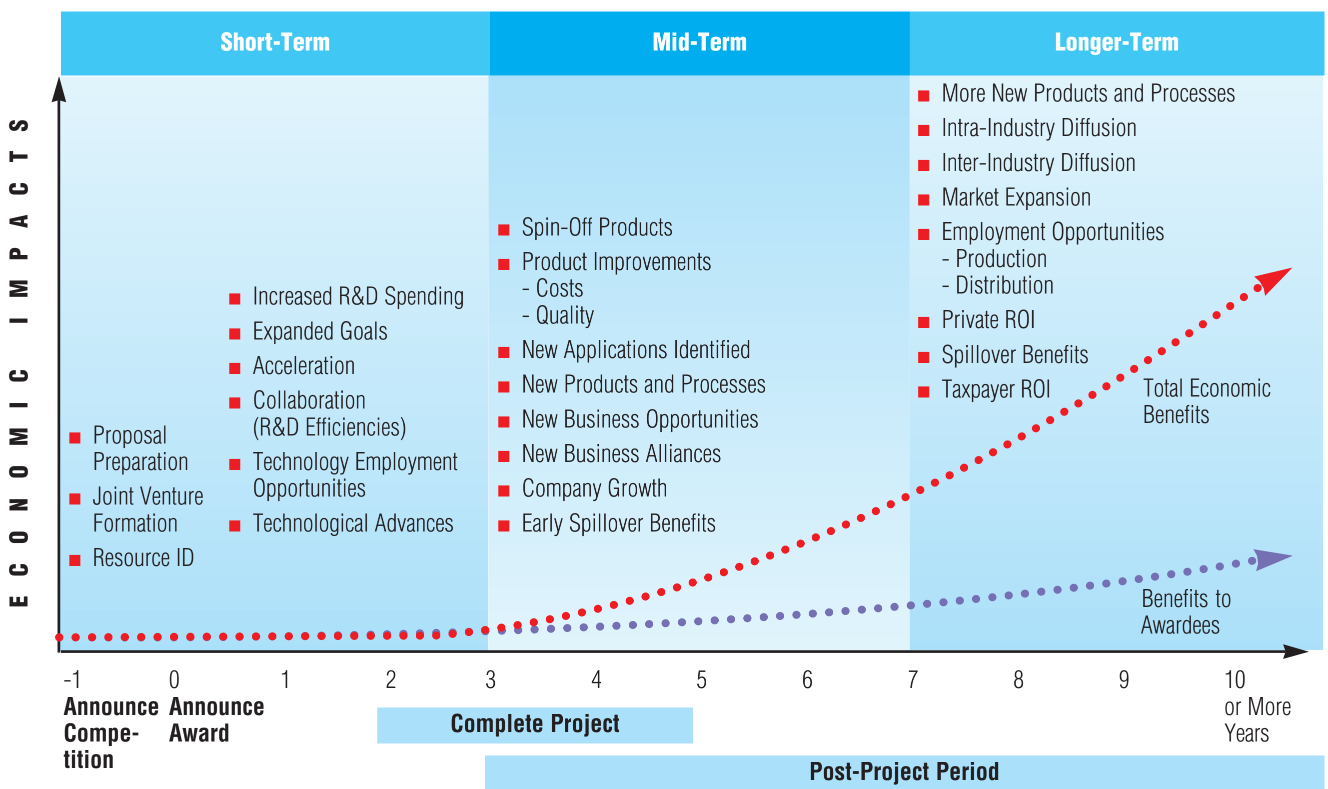
Activities and Impacts Within Firms

The following activities and impacts are related mainly to the award recipients: forming the initial idea; establishing collaborative research relationships; developing a research agenda; applying to the ATP for an award; carrying out the research; publishing results, filing for patents, and licensing the technology to others; conducting further post-ATP project research; attracting other sources of funding; conducting marketing studies and other precommercialization activities; forming new alliances for commercialization; developing products and processes that use the new technology; producing, selling and distributing the new goods or services; generating revenue; and building the business.[4]

Activities and Impacts in the Broader Economy

Activities and impacts that occur in the broader economy — outside the immediate influence of ATP award recipients — include receipt of benefits by purchasers of the new products or users of the new processes[5] in the course of their business operations, receipt of benefits by other companies that are able to imitate the technology or benefit in other ways from knowledge derived from the technology, and receipt of benefits by ultimate consumers of goods and services embodying the technologies.

Figure 2: Conceptual Timeline of ATP's Expected Impacts



(Source: Ruegg, 1999)

Timing of Activities and Impacts — A Conceptual Picture

Technology area, market conditions and the regulatory environment vary significantly across ATP-funded projects, and these differences can substantially affect the time path for the activities listed above. Hence, the time required for technology development, commercialization and diffusion varies greatly among the projects, even when they stay on track.

Figure 2 illustrates in concept how the time path of a successful project might unfold, starting with the announcement of a competition by the ATP.[6] On this conceptual chart, economic impacts are depicted on the vertical scale, and time on the horizontal scale. The lower of the two curves, rising from left to right, shows returns to the project innovators increasing over time as they commercialize it. The upper curve shows returns to the economy at large increasing as the technology diffuses into wider use. The difference between the two curves reflects benefits that "spill over" to those outside the project.

The chart is annotated with events that may lead, or contribute, to the generation of economic benefits during three time periods designated by the shading. Upon announcement of a competition by ATP, companies begin to prepare their proposal, form collaborative relationships, and identify resources. If they receive an ATP award, they tend to increase R&D spending, expand goals, accelerate research, hire scientists and engineers, and make technical progress.[7] These developments occur in the short-term, shown here as extending through to the approximate average project length of three years.

As a successful ATP project ends, the pace of commercialization activity surrounding the technology generally will pick up as depicted in the "mid-term" stage. Then, in the longer-term, wider diffusion of the technology — within the initially targeted industry and, for multi-use technologies, across industry sectors — is expected to occur as it is incorporated into new products and processes.

Two Specific Timelines — Differences and Similarities

Figure 3, on the next two pages, illustrates the specific time paths for two of the 38 projects. One project does not yet have a product or process on the market, the other does. One requires regulatory approval, the other does not. One company is publicly traded, the other is privately held. One is in biotechnology, the other is in computer software. Still, as shown in Figure 3, many activities appear in both timelines — but at very different times.

Medical Technology Requiring FDA Approval — Aastrom Biosciences

Growing out of research done by three faculty members at the University of Michigan in Ann Arbor, the idea of a bioreactor to grow human stem cells outside the body began to take shape in the mid-1980s. In 1988, the professors founded Aastrom Biosciences (while continuing their university research) and later brought in a partner with business experience. In 1991, with four employees, the company applied for an ATP award. Significant events for this project are shown in the top panel of Figure 3 on the following page.

After two years of research, Aastrom met the technical goals of its ATP project. Along the way the company invested heavily in protecting its discoveries by filing for numerous patents. It also submitted a substantial number of technical papers documenting its progress to professional societies and journals.

The technology for growing stem cells was embodied in the AastromReplicell™ Cell Production System (System). Because it will be used for human medical purposes, the System must be approved by the Food and Drug Administration (FDA), but only after successful completion of clinical trials and other tests. Several tests using human subjects have been conducted since the ATP project ended, with each test producing favorable results. If that success continues, the device will likely be approved and available for sale in the next one to three years.

The need for FDA approval creates a lag of several years between the start of commercialization efforts and the ultimate sale of the product. In this case, the effort is now in its 11th year, and the total time from concept to first commercial sale of the Aastrom System will likely be 12 to 14 years. Nevertheless, there are factors — including test results from cancer patients and the positive response of investors to Aastrom's stock offerings — which suggest that the technology has a very bright future.

Parallel Processor Computer Technology With Immediate Applications — Torrent Systems

The idea for this project came from the work and conversations of two computer programmers who formed a company in 1993 and applied the same year for ATP funding for a project which started the following year. The project made rapid progress in developing parallel processing technology, and it began to receive inquiries from potential customers about using the technology in new software applications. Torrent requested that the project be shortened so that the company could move quickly to commercialize products incorporating the new technology. Significant events for this project are shown in the bottom panel of Figure 3.

Unlike developers of medical devices, computer software vendors are not required to have any kind of approval to sell their products. Thus, Torrent was able to enter into licensing agreements with other companies a mere 18 months after starting its ATP project.

The huge difference in development times for these two technologies is illustrated in Figure 3, where key events are graphed against the same time scale. The first event for Aastrom's System was 12 years in the past, and broad economic benefits still lie a few years in the future. The first event for Torrent's new parallel processing technology was the company's founding in 1993, and customers were already using the product and receiving its benefits in 1996. Yet both projects stayed essentially on track and have largely continued to meet ATP's expectations.

Figure 3a. Aastrom Biosciences Example from the ATP 38 Project Sample — Successful Project, Slow Commercialization

	1988	1989	1990	1991	1992	1993
Economy-Wide Benefits						
Commercial Development		Incorporate Company				Enter Marketing Agreement with COBE CBT
Technical Development		Professors Continue Research at UMI			Enter Patenting Agreement with UMI	ATP Research Start Testing System with Human Subjects
Funding				Receive $1.2 Million Award from ATP		

*AastromReplicell™ Cell Production System

Figure 3b. Torrent Systems Example from the ATP 38 Project Sample — Successful Project, Fast Commercialization

	1988	1989	1990	1991	1992	1993
Economy-Wide Benefits						
Commercial Development						Incorporate Company
Technical Development						
Funding						

ATP Awards — Part of a Larger Funding Picture

For some projects, such as Torrent's, funding from the ATP constitutes a substantial portion of the total capital used to support research and development and, indeed, a substantial share of the overall costs. For most projects, including Aastrom's, ATP funds are a relatively small percentage of the total amounts that will ultimately be spent to bring the technology into use. Commercialization costs typically dwarf research costs. Nonetheless, ATP funding — targeted at a critical stage where technical risks tend to inhibit private investors — may be essential for ultimate success, as was the case for the Torrent and Aastrom projects.

Funding by the ATP has been shown by another study[8] to address two types of timing

1994	1995	1996	1997	1998	1999 (Projected)	2000 (Projected)
			60 Test Patients Benefitting			Large Number of Cancer Patients Are Helped
	Enter Marketing Agreement with Rhone-Poulenc		Enter Agreements to Manufacture System* Components		FDA Approves Patient Use of System* Start Selling System*	
Under Way	Apply for System* Bioreactor Patent Continue Testing System with Human Subjects		Report Clinical Results for Cancer Patients Receive Bioreactor Patent	Report Clinical Results for More Patients		
	Receive $35 Million from Rhone-Poulenc		Receive $21 Million from IPO Receive $11 Million from Additional Stock Offering			

1994	1995	1996	1997	1998	1999 (Projected)	2000 (Projected)
				United Airlines Starts Using the Product for Improved Scheduling Others Benefit from Use	United Airlines Increases Revenue by Millions of $	
	Develop Orchestrate™	Introduce Orchestrate™ to Market for Licensing	License Orchestrate™ to Additional Users Form Marketing Partnerships	IBM Partnership Integrates Hardware with Orchestrate™	Identify New Applications Form New Partnerships	
ATP Research Under Way						
Receive $1.2 Million Grant Award from ATP	Receive $3.8 Million in Private Capital	Receive $6.2 Million in Private Capital	Receive License Fees for Orchestrate™			

issues: overcoming an inability to start a project and speeding up progress needed to address a critical window of opportunity. Thus, even though ATP funds will in most cases amount to a relatively small share of the total costs expended to bring a technology to fruition, they can be a key factor in making it happen.

Of course, from an evaluation standpoint, multiple funding sources make the task of assigning cause and effect relationships more problematic. Which funding dollars caused what effect? One aspect of this study, therefore, has been to try to identify the role that the ATP has played in the developments to date.

Gains in Technical Knowledge

A major goal of the ATP is to build the nation's scientific and technical knowledge base. Each of the 38 completed ATP projects targeted a number of specific technical knowledge discovery goals, which are described in Chapters 2-8. Those chapters also briefly describe, in non-technical language, the technical advances of the 38 completed projects. More detailed descriptions of the research are available in the scientific papers and patent applications generated by the projects. The following section provides an overview of the wealth of technical knowledge generated by these projects.

A Host of New Technologies and Knowledge Gains

A number of new technologies have emerged from the 38 completed projects, and all of the projects have added something to the U.S. scientific and technical knowledge base. Even those projects that were not fully successful in achieving all of their research goals, or those that have not been followed by strong progress in commercialization, have achieved knowledge gains—of course, some more than others. Indeed, even the projects that were carried out by the several companies that have since ceased operations, or that have stopped work in the technology area, resulted in knowledge gains — albeit the direct market route of diffusion of the knowledge gains in those cases may be lost or postponed.

Advances were made in each of the seven technologies areas. In the field of electronics, advances were made, for example, in new processes and procedures for altering electrical properties of materials through ion implantation, for fabricating, testing and aligning extremely precise aspherical, multilayer-coated mirrors, for interconnecting thin-film integrated circuits, for constructing new devices utilizing the giant magnetoresistance effect, and for growing large silicon carbide single crystals.

In the field of information technology, examples of knowledge gains are embodied in new mathematical algorithms useful for restoration of digitized video images and for animated visualization, and in component-based software tools for building parallel processor applications.

In the field of biotechnology, knowledge gains include how to grow human stem cells outside the human body in large quantities at reasonable cost, how to deactivate viral contaminants in blood and other fluids, how to genetically engineer plant extracts, as well as techniques for rebuilding lost or damaged human tissues with engineered tissue.

In the fields of energy supply and environmental protection, knowledge gains are reflected in the new fabrication processes that were developed for superconducting materials; in the improved ability to control microstructure of aerogels, and in new methods of compatibilizing polymers for recycling.

Knowledge gains important to discrete manufacturing include new ways to measure and control dimensional variation in parts assembly, and intelligent thermal-error correction techniques for machine control. In the field of materials technology, knowledge gains led to new processes for safer, less costly near-net-shape gelcasting and new ways of producing optoelectronic polymers with desirable characteristics. Finally, in the field of chemicals and chemical processing, advances were made in multiphoton detection methods.

These and other technologies developed in the 38 projects are listed in Tables A1-A7 of Appendix A, column B, together with a listing in column C of commercial products or processes that are based on the technologies. This set of tables is provided for convenient, quick reference by the reader.

While the entries are arranged according to the seven technology areas which are used in Chapters 2-8, it should be noted that most of these projects and the knowledge developed in them do not lend themselves to easy classification. Most entail a mixture of technologies and interdisciplinary know-how; many could easily be put into one or more of the other categories shown. For example, the thermal-error correction technology is listed under "discrete manufacturing," but it could also fit well in the "information technology" category. As another example, the process technology for superconducting materials is listed under "energy and

Table 3. Outside Recognition of Technical Achievements in the First 38 Completed ATP-Funded Projects

Project Awardee	Year	Awarding Organization	Award
American Superconductor	1996	*R&D* magazine	One of the 100 most important innovations of the year.
American Superconductor	1996	*Industry Week* magazine	Technology of the Year Award.
Communication Intelligence #1	1997	Arthritis Foundation	"Ease-of-Use Seal of Commendation" for the development of natural handwriting technology, for use by disabled people who have trouble with keyboard entry.
DuPont	1993	*Microwave & RF* magazine	One of the Top Products of 1993, for high-temperature superconductivity component technology.
Engineering Animation	1994	*Computerworld* magazine	Smithsonian Award, for the use of information technology in the field of medicine.
Engineering Animation	1995	Association of Medical Illustrators	Award of Excellence in Animation.
Engineering Animation	1995	International ANNIE Awards	Finalist, together with Walt Disney, for best animations in the film industry.
Engineering Animation	1996	*Industry Week* magazine	One of the 25 Technologies of the Year, for interactive 3D visualization and dynamics software used for product development.
HelpMate Robotics	1996	*Discover* magazine	One of 36 finalists for Technology of the Year, for the HelpMate robot used in hospitals.
HelpMate Robotics	1997	Science and Technology Foundation of Japan	Japan Prize, to CEO Joseph Engelberger, for "systems engineering for an artifactual environment."
Illinois Superconductor	1996	*Microwave & RF* magazine	One of the Top Products of 1996, for cellular phone site filters and superconducting ceramics.
Illinois Superconductor	1997	American Ceramic Society	Corporate Technical Achievement Award.
Molecular Simulations	1996	*Computerworld* magazine	Finalist for Smithsonian Award, the 1996 Innovator Medal.

environment," but could fit well under "materials."

Another point to notice is the great diversity of technologies resulting from these projects. Knowledge gains range from mathematical algorithms underlying new software tools, to the science of growing human tissue, to new techniques for fabricating high-temperature superconducting devices. The diversity reflects the fact that all but one[9] of the projects were funded in the ATP's General Competitions, which cast a wide net for good ideas regardless of technology area.

Outside Recognition for Technology Advances

Although it is beyond the scope of this report to rate the degree of significance of the scientific and technical knowledge gained from the projects, various forms of recognition by other organizations indicate that outside parties see considerable value in the technical discoveries of some of the projects. Table 3 provides information about such outside recognition.[10]

Dissemination of New Knowledge

The pursuit of the tasks in a project usually produces a number of distinguishable outcomes. Projects generate new knowledge about how to apply underlying scientific principles to develop products or processes. If the technology is commercially successful, it provides the basis for products or processes that can be marketed. And with commercial success and dissemination of the newly gained knowledge comes the possibility of benefiting the economy in ways that go beyond the benefits received directly by the innovating firm.

Parties Other than the Innovator Can Benefit

If a project creates and disseminates new technical knowledge, parties other than the developers tend to benefit. That is true even if the new knowledge takes the form of "We tried to develop this technology using the following approaches, and we were unsuccessful." In that case, others may use this information to avoid pursuing comparable methods that would likely be wasteful. Or an underlying technology may be successfully developed even though a larger commercialization goal is not met.

New knowledge developed in a project can be diffused in a variety of ways. One way, discussed in the next section, is the marketing of new goods or services. Other ways relevant to the 38 completed ATP projects are publication by the U.S. Patent and Trademark Office (USPTO) of patents granted; registration of copyrights; interactions among research partners, suppliers, customers and others; preparation of technical papers that are published or presented at conferences; distribution of non-proprietary project descriptions by government funding agencies; and project-related workshops and meetings.

Public Disclosure of Patent Filing Information

When applying for a patent, an inventor must explicitly describe the invention. Because patent law requires that the invention be both novel and useful, the inventor must demonstrate that the invention is essentially different from any other invention and must describe how it can be used. When an application is filed, the USPTO discloses neither the application nor the fact that it has been filed. But when the USPTO grants a patent, the full application text describing how the invention may be used and how it is related to other technologies is put into the public record.

The decision to seek patent protection for intellectual property is influenced by many factors, including the ease with which others can copy the property's intellectual content and the difficulty of defending a patent position from infringers. Some companies, therefore, may decide that patent protection is not worth its expense, or they may decide that a strategy of trade secrets and speed to market is a more effective strategy. Or patents may be filed at an earlier stage in the process and trade secrets used in later stages.

The importance of patents as a strategy to protect intellectual property varies among technology fields. In some, particularly computer software, patenting is rarely a viable option. Among the six projects that involve only software, no patents have been granted and only one patent was sought.

In other fields patents are important, and many were sought for technologies that emerged from ATP projects. American Superconductor, for example, has received six patents for its ATP-funded electric-motor technology and has eight applications still under consideration.

Even when patent protection is sought, there are substantial differences across industries in the lag time between patent application and grant. Consequently, the absence of patents at this time does not imply that patents will not be granted in the future. An application may have been filed but the patent not yet granted.

In yet other fields, patenting typically occurs at the very early stages of a project, when the basic ideas are forming. The consequences of this fact might show an ATP-funded project without patent activity, because the ATP funding comes after the very early stages of the R&D efforts.

Even with all these considerations, patent statistics contain useful information about technology development and dissemination of the new knowledge. Fifteen of the projects have thus far been granted patents, with a total of 50 patents granted to them.

Figure 4 displays the number of projects which had different numbers of patent grants. Three projects each produced five or more patents. Two projects each produced four patents. Fifteen projects each produced at least one patent. For 23 projects, more than half, no patents have yet been granted.

For some projects, applications for patents have been filed but the patents have not yet been granted. The delay can be caused by a number of factors, such as the technology area and extent of review by the Patent and Trademark Office, among others. Figure 5 presents data for patent applications filed but

Figure 4. Distribution of 38 Completed Projects by Number of Patents Applied for and Granted

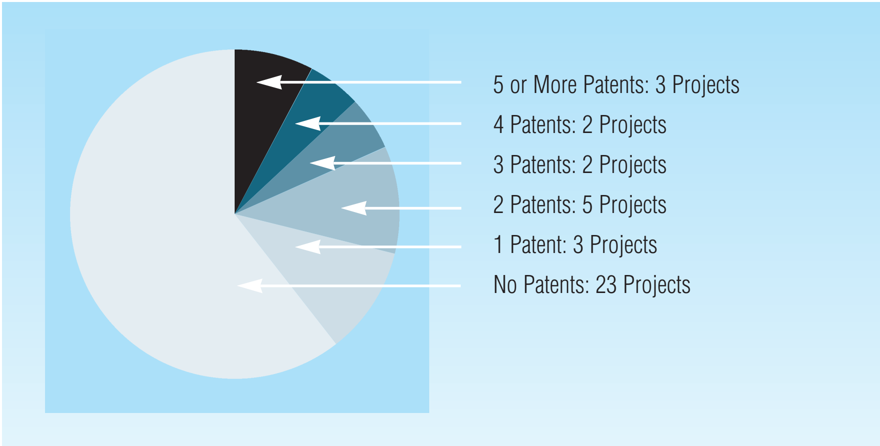
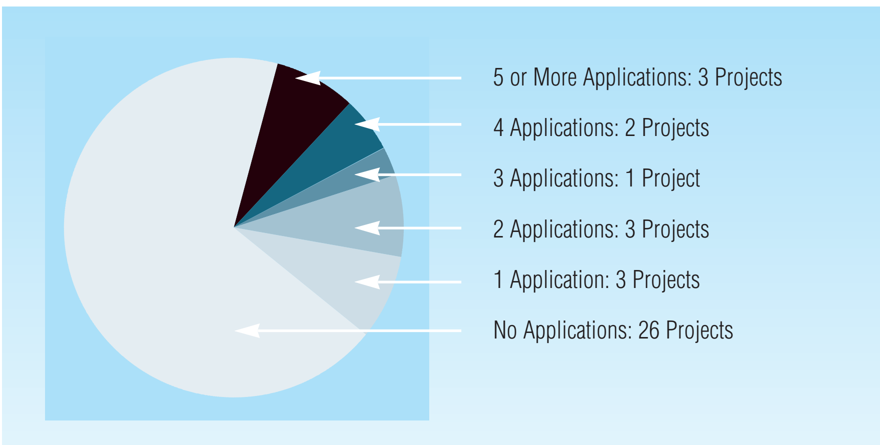


Figure 5. Distribution of 38 Completed Projects by Number of Patents Applied for But Not Yet Granted



not yet granted for the 38 completed ATP projects. For 12 projects, patent applications have been filed but patents have not yet been granted. The total number of outstanding patent applications is 51 for the 12 projects.[11] Three projects have five or more applications outstanding. For 26 projects, about two-thirds of the 38, there are no patent applications outstanding.

Eight of the 12 projects which have patent filings not yet granted are among the 15 projects which have already received patent grants; four of the 12 projects that have one or more outstanding patents applications have not already been granted patents. Thus, 19 of the 38 projects, or 50%, have engaged in patent activity for technologies developed with the ATP funding.

Copyrights and Registration for Software

The U.S. copyright system, also administered by the USPTO, works somewhat like the patent system but with important differences. A writer or other creator of a work or expression has an inherent copyright. The creator may register the copyright with the USPTO for added protection. For technology creations, protection via copyright is not as useful as patent protection. So when patenting is an option, it is usually chosen over copyright registration.

Registration of copyrights would seem to be important for ATP projects that generate computer software applications. Though six of the projects primarily entailed software technology, copyrights were not registered for any of them. In one case, however, the company is considering such a move to better protect its intellectual property.

Technology Transfer to Partners and Customers

If it conducts a project alone, a company can maintain a high level of secrecy about its technology. It may, however, develop technology in conjunction with three general classes of collaborators: joint venture members, subcontractors or informal partners. If it does so, it frequently shares technological information with these collaborators. In addition, the collaboration may be involve several types of partners: companies, universities, national laboratories, or non-profit organizations.

Providing a precise tabulation of collaborations across the classes and types of partners is difficult because of the many ways in which collaboration may be accomplished. Using a fairly broad definition of collaboration, it appears that for slightly more than half of the 38 projects, there was collaboration with one or more other companies. The next most prominent type of partner was the university, with about half of the projects involving one or more universities in the research and development effort. Government laboratories and non-profit organizations were each involved in less than a sixth of the projects.

For about two-thirds of the projects, there was an explicit arrangement for collaboration for at least one of the types of partners described above. In addition, some of the other projects had collaborative arrangements of a more informal nature that were not captured in the tabulation of research-related collaborations.

For the vast majority of new technologies, successful development and commercialization requires the inventor to also secure the participation of companies beyond those involved in the research. Some will be suppliers of inputs to the production process. Some will be partners in production. Others will be potential users and distributors of the new products or processes derived from the technology.

Table 4. Papers Published or Presented

Number of Papers	Number of Projects	Percentage[2]
0 or Unknown	22	58%
1-5[12]	9	24%
6-10	2	5%
11-20	4	11%
≥21	1	3%
Total	**38**	

Disclosure in Technical Presentations and Publications

Much technology is disseminated via the publication of papers in technical and professional journals. Through publication, the knowledge gained by participants in an ATP project is passed on to others outside the project. These recipients of the knowledge may then use it commercially. Publication of research findings is therefore frequently delayed until patents or some other kind of protection for the intellectual property has been secured.

Table 4 summarizes information about technical papers generated by the 38 projects. At least sixteen of the projects yielded publications (where the existence of publications is unknown, the project is counted in the "0 or unknown" line in the table), and five projects produced more than ten publications each.

Government Award Announcements, Workshops and Product Releases

When the government enters into an agreement with an organization, certain information about the agreement is generally made public. Such is the case with the ATP/company cost-sharing partnerships. Nonproprietary information has been disclosed to the public for each of the 431 projects funded by the ATP through 1998. The project information is available on the ATP web site on the Internet (www.atp.nist.gov), and new nonproprietary project descriptions are added to the site as new awards are made.

ATP Workshops

To help the public learn more about the projects it funds, the ATP organizes and sponsors numerous public workshops, where companies present nonconfidential aspects of their ATP-funded research and engage in open discussions. These workshops facilitate information flow in several directions — among awardee companies and from them to other companies, ATP project managers, other government program managers, the press, potential investors, and universities.

Knowledge Gained From Product Use or Examination

When a good or service that incorporates new technology is delivered, the buyer often will be able to learn a great deal about the technology. The mere functioning of a new product will reveal some information about the technology. Intentional investigation into how the product works will reveal more. Taking it apart, sometimes called reverse engineering, will reveal even more. For 24 of the 38 projects reviewed for this study, some commercial products or processes based on the ATP-funded technology are already on the market, where through use or examination they are providing others with information about the new technologies.

Commercialization of the New Technology

New technical knowledge must be put to use if economic benefits are going to accrue to the nation. In most instances, the use will be through the introduction into the market of a new product or process by the inventing firm or other companies. The new knowledge may be used by outside researchers before it makes its way onto the marketplace. But the new knowledge must eventually result in new products or processes in the marketplace for there to be real-world benefits to the economy.[13] In competitive markets, the producer is typically unable to capture all the benefits of a new product, and the consumer reaps part of the benefits.

Commercialization — A Critical Step Toward National Benefits

For 24 of the 38 completed projects, a new product or service is on the market or a new process is being used to improve the quality or reduce the cost of making an existing product or service. Eighteen projects have introduced new products, five are using new processes in their own production, and one has introduced a new service. All of the products and processes are used by commercial companies in their production processes.

Among the new products are substantial devices that are self-contained, including receive filters for cellular phone sites, lasers that can be tuned to different wavelengths for a wide range of applications, flat fluorescent lights to serve as back-lights for color liquid crystal displays in a variety of applications, wall units made of mixed recycled plastics for use in pre-fabricated buildings, robots to provide delivery services in hospitals and other installations, machine tools that can produce much higher quality metal parts because they are self-adjusting for the effects of high heat that otherwise would cause errors, and a super-sensitive measurement instrument for detecting minute amounts of viruses and toxic chemicals in medical and environmental applications.

Several of the new products are much smaller devices, commonly viewed as components in other products. These include controllers and fiber-optic collimators for wavelength multiplexers, cheaper blue light-emitting diodes for inclusion in full-color displays, epitaxial laser wafers, giant magnetoresistance sensors for automatic brake systems and other applications, high-temperature superconducting (HTS) wiring for connecting super-cooled electrical devices to ordinary devices, thin-film HTS components for magnetic resonance imaging equipment in hospitals, and minute porous glass components in sensors for toxic gases.

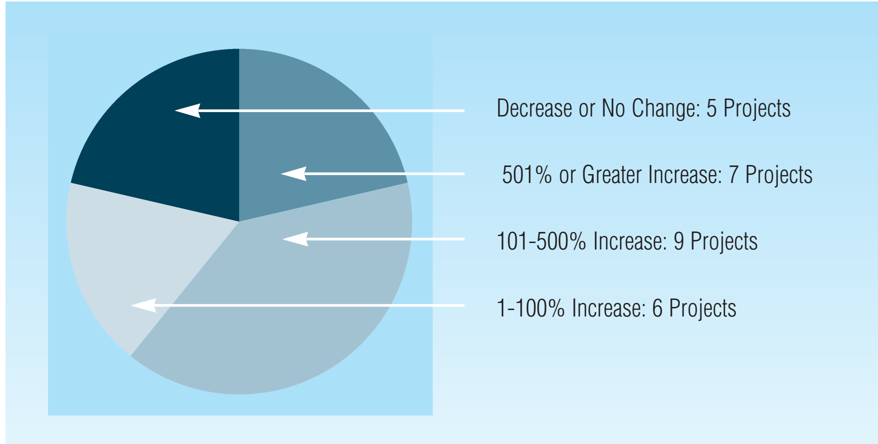
Additional new products and a new service have resulted from research in the computer software field. These include a pad and stylus system for allowing the input of handwritten characters into computers, detailed images and dynamic presentation of the inner parts of the human body for CD-ROMS and books used in medical education, a programming tool that makes the development of programs for parallel processing computers much easier, a system that produces rotatable three-dimensional views of very complicated molecules for a number of applications in the chemical and drug industries, a user interface for use in sharing product model data, and a service that helps producers and archivers of movie films improve film quality by removing blemishes from film masters.

Finally, there are new processes that improve the manufacturing of a variety of products. They include processes for the epitaxial growth of semiconductor components, the implantation of ions of various materials on large silicon crystal wafers in a much cheaper way, the production of very high quality spherical and aspherical mirrors for use in photolithographic and other fabricating equipment, and the assembly of automobiles which are of higher quality because stamped metal parts fit together better.

For a convenient, quick reference by the reader, brief descriptions of the new products or processes are listed in Tables A1-A7 in Appendix A, in Column C. For each new product or process, the new technology on which it is based is also listed in the Appendix A tables, in Column B.

Commercializing a technology is an important step, but it does not mean that the project is necessarily a full success from the perspective of either the company or the ATP. Some products have been sold for testing and evaluation, and after testing, the purchaser may decide not to place a larger order. Other sales are by struggling companies that may fail in the future, even if the product is a good one. Widespread diffusion of the technology may or may not ultimately happen, but it is significant that these products and processes are actually on the market. This is an extremely important step for the eventual generation of broad-based benefits for the economy as a whole.

Figure 6. Distribution of 27 Completed Projects at Small, Single-Applicant Companies by Percentage of Employment Change



Rapidly Growing Companies

The introduction of a new or improved product into the market is clear evidence of commercialization. Even before that happens, however, other indicators can signal that a company is probably on the path toward commercialization. One of these is company growth, and some limited data on this performance "indicator" is provided in Figure 6, which focuses on employment at the small, single-applicant companies. Employment changes in joint ventures, larger companies and nonprofit organizations are less closely tied to the success of individual research projects, and, therefore, they are not shown in the figure.

Clearly, this group of companies as a whole has grown rapidly, as measured by employment growth rates. All but five of the 27 small companies at least doubled in size; one company grew 1,900 percent. Employment at four companies actually declined, while it remained constant at one company.

Companies "Going Public"

Another development that is useful in assessing commercial prospects for small companies is the initial public offering (IPO) of stock by a company whose stock has heretofore been privately held. For the most part, these are start-up or near-start-up companies.

This event is relevant for the 21 single-company applicants that were privately held at the beginning of their ATP funding periods. Seven of the 21 companies filed IPO statements with the Securities and Exchange Commission (SEC). Five of them conducted IPOs during their ATP funding periods. In addition, one company conducted an IPO in early 1998, after project completion.

Another company, in filing the required form with the SEC, noted its intention to conduct an IPO and has since been acquired by a larger company, at an apparent substantial premium over the approximate value placed on the company at the time of the SEC filing.

Conducting an IPO subjects the company to the scrutiny of stock market analysts and to the financial decisions of investors. It is a demanding test of whether the capital market believes the company has a promising future. Even announcing the intention to conduct an IPO invites potential investors to examine the data presented by the company in its SEC filing, and only infrequently do companies announce intention to file without following through.

Broad-Based Economic Benefits

The actual use of new products and processes that result from a new technology generates a variety of benefits for the economy. These benefits may result from lower costs or higher quality relative to products and processes they replace. Or they may stem from unprecedented performance capabilities, such as a novel treatment for cancer. Those who receive these "incremental" benefits typically do not pay for their full value.

What Effect Did ATP Have on the Project?

Before turning to economy-wide benefits, it is useful to consider the impact of ATP funding on the research that led to them. Project leaders from each company were questioned about the role ATP funding played in their projects. Their answers are presented in the detailed discussions of Chapters 2-8 and summarized in Table 5.

For all 38 completed projects, awardees were asked whether the project would have been done at some point without ATP funding. Answers were received for 32 of the projects.[14] For 21 of them (66%), the companies and other organizations indicated they would not have done the project at all without ATP funding.[15] For the other 11 projects, they said they would have done the project at some later date or slower pace. For the 32 projects as a whole, none would have been completed in the same time frame without ATP funding, and 21 of them would not have been completed at all, according to officials at the companies and other organizations.

For the 11 companies whose projects would have been delayed without ATP funding, the typical lag reported was about two years, with a wide variance around the average. A lag of just 24 months may seem short, but its effects can be substantial when the costs and benefits of accelerating the technology development are considered. For illustrations, see the detailed treatments of two ATP projects, Aastrom Biosciences and Tissue Engineering, later in this section, where acceleration of the availability of new medical treatment technology is shown to have a potentially large impact on societal benefits.

Receipt of an ATP award also enhanced the ability of some of the companies to raise additional capital and acquire partners. Thirteen of the 32 responding companies reported that the ATP award helped them raise additional capital (four of them were among the companies that conducted an IPO after receiving ATP funds), and 23 said it boosted their ability to find partners.[16]

Assessing Private and Social Returns from New Technology

Counting the number of projects that would not have been done without ATP funding provides some limited information on the benefits of the program, as does tabulating the number of months that projects would have been delayed if they would have been done, but on a delayed schedule. These limited data are insufficient to assess whether the ATP awards for the 38 completed projects were good uses of public funds, however. More detailed assessment is needed.

The value of the ATP-funded research can be assessed by probing the benefits and costs of projects and the return on the ATP investment. It should be kept in mind, however, that full diffusion of technologies generally takes considerably more time than has elapsed for these projects, and at this time their ultimate, long-run outcomes cannot be known with certainty.

The Mansfield Study of Private and Social Returns

More than 20 years ago Professor Edward Mansfield[17] of the University of Pennsylvania established general procedures for economists to follow when compiling estimates of the private and social returns from groups of innovations (new products or processes). His work focused on estimating "consumer surplus" benefits to consumers of new and improved goods and services resulting directly from commercial activities of the innovators — a type of spillover effect.

Mansfield's method and estimates addressed market spillovers and those knowledge spillovers which generate benefits via the development of new or improved competitive goods and services by imitators of the original

Table 5. Impact of ATP Funding on Conducting Projects

Would Have Proceeded Without ATP Funding	Number of Projects	Percentage
Yes, But at a Slower Pace, with Delay of[18]	11	34%
• 18 Months	4	
• 21 Months	3	
• 24 Months	3	
• 60 Months	1	
No	21	66%
Total	**32**	

innovating companies. He did not address other kinds of knowledge spillovers, such as use of the new knowledge in a research process leading to other new technologies in a different industry. Hence, for the type of enabling technologies that ATP funds, Mansfield's approach could be expected to capture an important, but partial, share of the total impact.

Case Studies of Seventeen Innovations

Mansfield based his analysis on 17 extensive individual case studies. His procedures have been upgraded over the years, but they still constitute a good starting point for any empirical study of the effects of innovation. He and his colleagues collected annual data for: cost, revenue and profits from the innovating firm; cost, revenue and profits from other firms in the same industry for competitive products or processes they introduced after imitating the new product or process; cost, revenue and losses from the innovating firm or other firms in the industry for products or processes the new product or process supplanted; cost, revenue and profits for producer goods from other firms that purchased the new product or licensed the new process; and cost and benefit data from final users for consumer goods.

Once these data were in hand, they were used to calculate: the annual costs of the innovation; the annual private dollar returns to the innovator; the annual dollar returns to all other parties (competitive firms, purchasing firms, final users); the net annual social dollar returns, by summing all these annual dollar returns (netting out any negative values); the annual private dollar return (using data for the innovating firm alone); the private rate of return; and the social rate of return.

Data Requirements for the Mansfield Analysis

The landmark results published by Mansfield, et. al., have been cited numerous times in the economics and technology policy literature, usually in the context of examining differences between the private and social returns from innovation. The focus here, however, is on a different aspect — the amount of data required to support his analysis. Table 6 presents data from the Mansfield study showing when the 17 innovations entered the market and how many years of data were available for the empirical estimates. In most cases, Mansfield was able to draw on 11 to 18 years of historical data for the older innovations. For more than a third of them, however, some projected data were used.[19]

Sufficient Data for Analysis of 38 Completed ATP Projects not Yet Available

Few data of the type collected in the Mansfield study exist for new products and processes generated by the 38 ATP projects, since the technologies are still so young. Most of these innovations have multi-application potential, making their evaluation even more complex. And most of their benefits and many of their costs are yet to come. Economists can, nevertheless, project the values of these items (as Mansfield, et. al., did in some cases) in order to calculate the private and social returns. The earlier an analysis is conducted, relative to the year of the innovation, the greater the necessity to use projected data and, consequently, the greater the uncertainty in the results. Uncertainty in results is unavoidable at this time for benefit-cost evaluations of this kind for ATP-funded projects.

After a sufficient number of years have passed, an exercise like the Mansfield study — relying on more years of empirical data — can be performed for the innovations that emerge from these 38 ATP projects. That exercise will be much easier if data are collected and carefully archived along the way. The ATP is doing that as part of its evaluation plan.[20]

Table 6. Years of Data Available for Estimating Effects of 17 Innovations, Mansfield, et. al. (1977)

Market Entry	Number of Innovations	Years of Data
1955	1	18
1958	1	15
1962	5	11
1965	4	8 or 15
1968	3	12
1972	3	8

A Portfolio Approach to Costs and Benefits for the 38 Projects

The ATP awarded $64.6 million to the 38 completed projects described in Chapters 2-8 and contributed another $9.4 million to the 12 terminated projects (see Appendix B), bringing total ATP spending on the 50 projects completed or terminated by March 1997 to $74.0 million.

Since it is not expected that every project will be fully successful — all research goals reached, commercialization achieved, widespread dissemination of the knowledge and extensive benefits realized from the use of the resulting goods and services — it is more reasonable to assess the effectiveness of ATP awards as a group of funded projects, as an "investment portfolio," much as an investor in stocks and bonds might do. Pursuing that line of thought with the combined set of 50 completed and terminated projects leads to a simple question: For its investment of $74.0 million, what has the public received, or is likely to receive, in return?

Expected Returns for Just Three of the Projects

This study did not attempt to estimate returns to project participants or to society for the entire portfolio of 38 projects. To do so would entail an involved process requiring detailed economic evaluation case studies and a much larger effort than was allocated for this report. But for three of the projects, such detailed estimates have been calculated by other researchers.[21]

Aastrom Biosciences: Stem-Cell Therapy Cost Reductions

The availability of ATP funds enabled Aastrom Biosciences to achieve its results one to two years earlier than it would have otherwise. This finding implies that benefits from the use of the company's new AastromReplicell™ System would start one to two years sooner.

Benefits of several kinds are expected to result from use of the System, as noted in Chapter 2. One of these is a reduction in the cost of stem cell therapy for cancer patients after chemotherapy or radiation treatments. Other benefits are reductions in the patient's pain and in the risk of complications.

Economists at the Research Triangle Institute (RTI), a consulting firm in North

Carolina, have calculated estimates of the value of accelerating the availability of the System, using only the reduction in procedure cost.[22] RTI economists estimated the number of cancer patients who would use the System in its first year of availability (16,000), estimated the annual growth in applications of the System, determined the cost reduction per patient, and used conventional present-value calculations to get a current value for the cost reduction effect. RTI conducted the calculations assuming the System would be available with ATP funding at the beginning of the year 2000 and repeated the calculations for the "without ATP funding" case that assumes the Systems would be available 18 months later.

RTI estimated that the System, once implemented, would save about $87 million (in 1997 dollars) in medical treatment costs without the acceleration provided by ATP support and $134 million with the acceleration. The difference, $47 million, is the estimated additional value, in terms of cost savings, created by the ATP funds, based on this one application area. Other applications of stem-cell therapy using the System are also expected, which will likely add to the future benefits.

This estimate considers only cancer treatment cost savings. Besides these benefits, the typical patient is expected to have less pain, suffering and trauma when stem cells are collected if the System is used instead of an alternative procedure. However, the value of the pain and trauma reduction is not included in the calculations because data for those effects were not available.

It is also expected that the stem-cell mixture that is injected back into the patient will be freer of cancer cells, leading to a better eventual outcome, if the System is used, but value was not assigned in the RTI study to that beneficial effect, either. Finally, with lower cost and less trauma, stem-cell therapy might become a possibility for some cancer patients who would otherwise not receive it. Stem-cell therapy is expected to increase survival chances for some of these patients, but the value of their prolonged lives is also not included in the estimate.

According to the estimates calculated by RTI, we can expect the additional returns to society attributable to ATP's award to Aastrom Biosciences to be on the order of $47 million, at least. Funding by ATP for the Aastrom project was $1.2 million. And the contribution by ATP to all 50 completed and terminated projects was $74.0 million. Since the RTI estimates from the use of the Aastrom System product were based on only one of several kinds of potential benefits, it seems clear that returns from this project alone are likely to account for a substantial percentage of the ATP expenditure for all 50 projects.

Auto Body Consortium: Higher Quality Car Bodies

While the economic and social impact of the Aastrom System is almost entirely in the future, the Auto Body Consortium's ATP project is already producing measurable benefits, as noted in Chapter 4. Chrysler, a member of the consortium, is making its Concorde line with the new dimensioning technology, as discussed in its marketing literature. Cars in this line are assembled in a plant that has already implemented the new technology and has the capacity to assemble about 250,000 cars per year. To date, the new technology has been implemented in six of the 10 Chrysler plants in North America, and each is expected to produce a minimum of 200,000 cars in 1998.

In a detailed study of this ATP project, Consad Research Corporation (Consad), a consulting firm in Pittsburgh, Pennsylvania, estimated a range of $10 to $25 per vehicle in production cost savings.[23] Multiplying the smaller number ($10) by the minimum number of cars to be assembled in the six Chrysler plants yields an estimate of at least $12 million in production cost savings for 1998 alone. Multiplying by the larger number ($25) results in a savings estimate of $30 million.

Every one of those cars produced in 1998 will also cost less to maintain, with the producers saving on warranty costs and consumers saving on out-of-warranty costs. Consad estimated maintenance savings of $50 to $100 per car over its life, implying that for these 1.2 million cars (six plants producing 200,000 cars each), between $60 million and $120 million in maintenance costs will be saved over the life of the cars. Only a small portion of those maintenance savings have been realized so far, because none of these cars has been on the road for much more than a year.

Actual current savings have also already been realized by General Motors, the other automobile assembler involved in the project. The new technology has been implemented in 16 of its 31 plants in North America. Since the number of cars produced per plant by GM is comparable to that by Chrysler (at least 200,000 per year), GM will realize production cost savings of at least $32 million in 1998, and the figure could be as high as $80 million. And maintenance savings over the life of these cars would be between $160 and $320 million.

The estimates do not take into account cost savings from extending the technology to the other 4 Chrysler and 15 GM plants. The savings for those additional plants are still in the future, but the likelihood of these savings occurring in the U.S. economy is high.

Once again, a comparison with the size of the portfolio investment is in order. At least $44 million ($12 million at Chrysler and $32 million at GM) in production cost savings were expected to be realized in 1998 alone. The savings could be as high as $110 million. Comparable savings at the six Chrysler and 16 GM plants in 1999 and beyond are expected, as well. The Consad study projected economywide benefits of about $3 billion in the year 2000 due to resulting quality improvements in U.S.-produced automobiles and associated market share gains.[24]

Tissue Engineering: New Materials to Repair Damaged Ligaments

The availability of ATP funds enabled Tissue Engineering to achieve its results two years earlier than it would have otherwise, as noted in Chapter 2. RTI, which also included this project in its detailed case studies,[25] estimated that products using a new prosthesis material — animal-derived extracellular matrix, or ADMAT — based on technology developed by Tissue Engineering with ATP support, would reach the market in 2001.

The RTI study focused again on a single application of ADMAT in calculating benefits from the use of this technology, namely, the repair of damaged knee ligaments (specifically, anterior cruciate ligaments, or ACLs). To estimate the number of potential users, RTI questioned officials at Wright Medical Technologies, a partner with Tissue Engineering, who provided an estimate of the number of persons who damage their ACLs annually. Based on that estimate, RTI estimated that the number using the Tissue Engineering technology would start at 9,000 in the first year of availability and grow to 72,000 10 years later. In addition, the RTI study explicitly incorporated benefits from the improvement in the quality of life for such persons, using a "quality-adjusted-life-years" index value.

RTI concluded that the total benefit to persons who receive the treatment is expected to approximate $33 billion with the support of the ATP funds. Without that support, it is expected to be on the order of $18 billion, because without the ATP funding benefits are not expected to start to accrue until 2003. Thus, about $15 billion of the expected net benefits from the new technology was estimated to be attributable to ATP funding.[26]

The difference in the sizes of RTI's estimated benefits from uses of the Aastrom Biosciences and Tissue Engineering technologies occurs for two major reasons. One is that the number of potential users of Tissue Engineering's ADMAT (patients with ACL damage) is larger than the number of potential candidates for bone marrow transplantation using Aastrom's System. The other is that the estimated patient benefits for ACL repair includes an estimate of the value of improvements to the patient's quality of life, whereas the estimates for bone marrow transplant benefits reflect only treatment cost savings and include no values for physical benefits to the patient.

These estimates for benefits to be received by users of the Tissue Engineering technology are so much larger than the ATP contribution to the project — $2 million — that making a comparison seems beside the point. What seems clear, though, is that the expected benefits appear to be much larger than the cost expended to achieve them.

Projected Benefits From ATP Contribution in Three Projects Exceed Total ATP Costs

The value of the projected benefits resulting from the ATP contribution in just the three ATP projects profiled above would greatly exceed total ATP costs to date. Cost savings already realized by Chrysler and GM as a result of the Auto Body Consortium project appear likely to be larger than the $74.0 million that ATP put into all 50 projects addressed in this report, not to mention the larger gains to the economy from quality improvements. If Aastrom Biosciences succeeds in bringing its product to market and if the RTI estimate of the value of the acceleration of market availability proves accurate, the return from ATP's assistance to the Aastrom project alone would cover more than half of all ATP funds provided for these 50 projects.

In addition, the estimated social return attributed to the ATP for the Tissue Engineering project is in the billions of dollars. The value of those benefits obviously swamps the $74.0 million in ATP funding for the 50 projects. Indeed, if the ADMAT technology proves to be anywhere nearly as beneficial as the RTI estimates predict, its benefits would swamp all ATP funding for all projects since the beginning of the program. Even if the expected number of patients who would benefit were cut, for example, by 80 percent and the expected benefit per patient were reduced by a like percentage, the estimated return from the ATP's contribution to this technology would still be more than half a billion dollars.

Potential Benefits from Other Projects

Based on the investigations of projects conducted for this study, considerable evidence suggests that others among the 38 projects are also quite promising in terms of their future benefits potential.

To mention only a few of the additional promising technologies that have resulted from this first group of 38 completed projects, consider first the Torrent Systems Project. It was found, for example, that an early user of its computer software technology expected to generate between $50 and $100 million per year in increased revenue on a $17 million investment in a system incorporating Torrent's technology, and that other users were also adopting the technology.

As another example, it was found that the software technology of Engineering Animation is being used to improve the training of doctors, among other things, and that patients in a particular surgical procedure were having better outcomes as a result of the company's imaging software. To these we can add other projects that were found to have produced promising technologies — technologies that may facilitate better weather forecasts, improve communications, enable new drug discovery, improve electronic devices, and lower loss of limb and life globally by improving detection of old land mines and toxins.

Preparing the Way for Future In-Depth Studies

Although this study does not provide a detailed quantitative analysis of the benefits deriving from these 38 completed ATP projects, it does document a number of project performance characteristics that will be useful for detailed estimates of returns. The presentations of project status in Chapters 2-8 contain many references to relevant markets, the role that the technology plays in those markets, the position of the innovating firm relative to other firms in the vertical chain leading to final purchase by users, and other characteristics that would be used in such a study. It also documents progress as of a point in time.